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The Design and Application of MIDAS: A Constructive Simulation for Human-System Analysis

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Summary A unique tool for crew station human engineering design and analysis has been developed at Ames Research Center. Called MIDAS, this workstation-based simulation system contains models of human performance which can be used to evaluate candidate crew procedures, controls, and displays prior to more expensive and time consuming human subject experiments. Several aviation applications have demonstrated MIDAS' ability to highlight procedural or equipment constraints and produce human-system performance measures early in a platform's lifecycle. Guided by lessons learned from these applications, MIDAS is undergoing major architectural and model content expansion prior to entering a period of formal usability and model evaluation. The software design, behavioral representation, and use of MIDAS are reviewed, emphasizing the expanding role for constructive simulation in the engineering of human-machine systems.

1. INTRODUCTION

The U.S. Army, NASA, and Sterling Software Inc. have developed a software system for aiding the design of advanced aircraft cockpits. The Man-machine Integration Design and Analysis System, or MIDAS, combines graphical equipment prototyping, a dynamic simulation, and human performance modeling with the aim to reduce design cycle time, support quantitative predictions of human-system effectiveness, and improve the design of crew stations and their associated operating procedures.

As an exploratory development program, the MIDAS software has progressed through seven development phases which culminated in capabilities demonstrations. Recent effort has included not only increasing the depth and range of human performance elements, but also applying the emerging system to specific platforms and operational problems. While MIDAS fundamentally remains a research program to advance human performance modeling, considerable emphasis has been placed on usability, software standards, and collaborations with users. The system architecture, human performance elements, and applications of MIDAS are described below.

1.1. Background and Assumptions

Several key findings and assumptions have guided the development of the system:

1) Flexibility to address evolving uses of the tool was a major design goal. Isolating detailed requirements from potential MIDAS users proved to be difficult, as crew station design was found to be as much an art form as an engineering practice. One study sponsored by the program found that rotorcraft cockpit design required input from over 40 distinct specialties, ranging from anthropometry to optics to research psychology [1]. Supporting this practice would require a wide range of static and dynamic output measures, depending on the analyses sought.

2) A temporal basis for the behavioral simulation was selected. While many discrete event simulations use an event-based approach, most human performance data relies upon time based measures. Further, a discrete time or tick-based simulation provided a more straightforward sequencing and synchronization of models, particularly those associated with graphics visualization. Finally, time as a control construct allowed an easier integration of differing grain size models, since execution time was the most ubiquitous referent for the components anticipated.

3) MIDAS was incrementally populated with models of sensory, cognitive, and motor response behavior in a deliberately incomplete fashion. It was not possible to produce a single, integrated human model, nor even a comprehensive suite of individual performance models, which addressed most human behavior relevant to cockpit design [2]. Far too many aspects of skilled performance were not fully understood, and many which had empirical or theoretical underpinnings were difficult to generalize. As a result, the models and constructs within MIDAS were selected based on their likelihood to aid known design questions and their availability. The system can represent portions of a wide range of operator behavior, however the modeling is comprehensive only for a subset of typical mission tasks. MIDAS is intended to supplement, not replace, full mission, human-in-the-loop simulators. Therefore the simulation focus has been 10 to 25 minutes scenario segments, in which the human-system interaction for that segment could be modeled in detail.

2. DESCRIPTION OF THE SYSTEM

A user's perspective of MIDAS, emphasizing inputs and outputs, is shown in Figure 1 below. The existing system contains a set of integrated software modules, editors, and analysis tools produced in C, C++, and Lisp, with an architecture based in agent-actors theory [3].

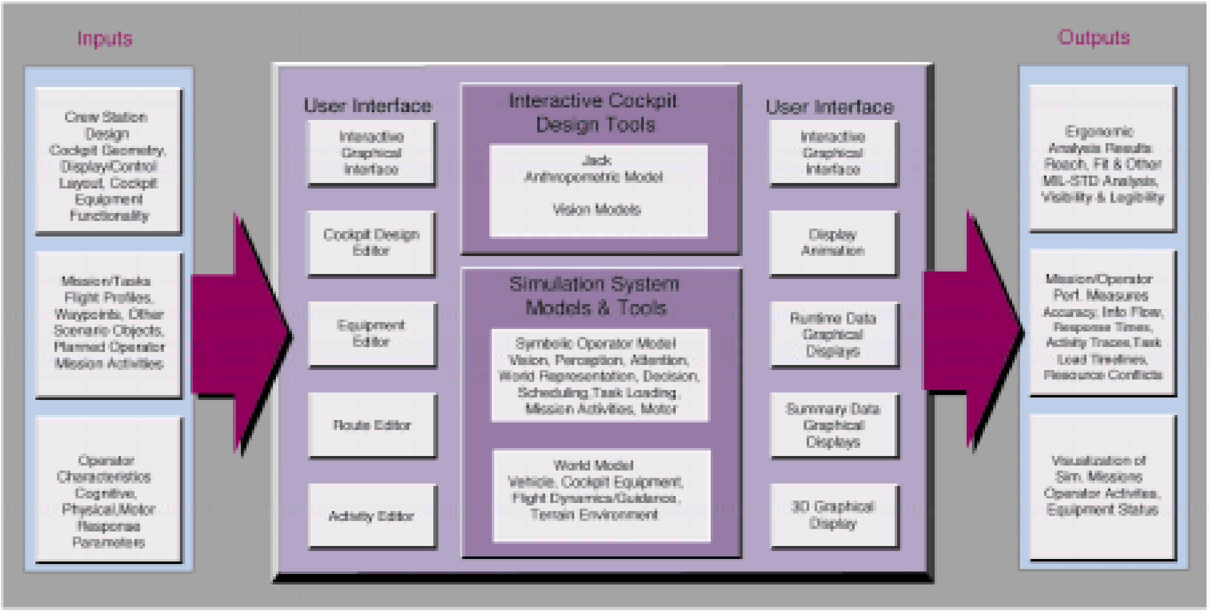

Figure 1: User View of MIDAS

Each major component, or agent, contains a common message passing interface, a body unique to that agent's purpose, and a common biographer structure which keeps track of important state data or events for analysis. This uniform representation was chosen to provide modularity. The total system contains 350,000 executable lines of code, with about half of the total associated with a dynamic anthropometry model.

Once a user inputs or specifies operator, task, and equipment characteristics, MIDAS operates in two major modes. The first, Interactive Mode, supports scenario-independent layout of the crew station for assessments of visibility and legibility, examination of anthropometric characteristics, and analyses of cockpit topology and configuration. The output of MIDAS in this mode corresponds to cockpit geometry and external vision design guides, such as MIL-STD-1472 and AS-580B [4] [5].

The other analysis path supported by MIDAS is a dynamic simulation. The Simulation Mode provides facilities whereby specifications of the human operator, cockpit equipment, and mission procedures are run in an integrated fashion. Their execution results in activity traces, task load timelines, information requirements, and mission performance measures which can be analyzed based on manipulations in operator task characteristics, equipment, and mission context. A summary of the MIDAS model content, behavior, and flow of information during a simulation is provided below, with a more complete description available in Corker and Smith. [6]

2.1 Cockpit Equipment/World Representation

Using geometry either produced internally or imported from a commercial CAD system, MIDAS supports a graphical representation for the physical entities in an environment. These entities are produced and held in a allowing dynamic prototyping of virtually any 3-D entity. In addition to their physical aspects, the functionality of controls and displays is captured by associating operating procedures and behaviors to each graphical equipment component. User-tailorable from a library of primitive equipment types, these functional models are expressed in three different formats: a time script, a stimulus-response, or a finite state machine representation, depending on the fidelity desired. In addition to the physical and functional models for a cockpit, the entire crewstation can be placed inside of a vehicle model, linked to guidance and control models, and placed inside a terrain database or gaming area.

2.2 Human Operator Representation

The most challenging constructive modeling task is characterizing the perception, decision making, and response of an operator as they interact with a simulated system. The human operators represented by MIDAS contain the following models and structures.

2.2.1 Physical Representation

A model of human figure anthropometry and dynamics has been developed at the Center for Human Modeling at the University of Pennsylvania. The model, Jack®, represents human figure data (e.g., size and joint limits) in the form of a 3-D mannequin which dynamically moves through various postures and visual fixations to represent the physical activities of a simulated human operator [7].

2.2.2 Perception and Attention

The simulated human operator is situated in an environment where data constantly streams into the operator's physical sensors. While auditory, haptic, and proprioceptive systems serve important roles in the operation of vehicles, MIDAS has focused on modeling perception agent computes those environment or cockpit objects imaged on the operator's retina, tagging them as in/out of peripheral and foveal fields of view, in/out of an attention field of view, and in/out of focus, relative to the fixation plane. Objects in the peripheral visual field are partially perceived and attentionally salient changes in their state are available for further processing. In order for detailed information to be fully perceived, the data of interest must be in focus, attended, and within the foveal vision for 200 ms. The perception agent also controls simulation of commanded eye movements via defined scan, search, fixate, and track modes. Differing stimuli salience are also accommodated through a model of pre-attention, patterned after the work of Remington and Johnston [8], in which specific attributes, e.g. color or flashing, are monitored to signal an attentional shift.

2.2.3 Updatable World Representation (UWR)

In MIDAS, the UWR provides a structure whereby simulated operators access their own tailored or personalized information about the operational world. The structure and use of the UWR is akin to human long term memory and is one of the aspects of MIDAS unique from most human-system modeling tools. UWR contents are defined by pre-simulation loading of required mission, procedural, and equipment information. Data are then updated in each operator’s UWR as a function of the mediating perceptual and attentional mechanisms previously described. These mechanisms function as activation filters, allowing more or less of the stimuli in the modeled environment to enter the simulated operator’s memory. A semantic network is used to organize perceptual data and knowledge in an UWR, and contains objects, called nodes, that represent concepts about the data. Relationships among nodes are expressed as links, and assigned by a user for relationships that the analyst or designer considers critical, e.g., “is-displayed-on” or “contains.” The links among these nodes have a strength of relatedness, and this weight governs an associated model of memory decay, which is implemented as an exponential function indexed by the time of last update or access.

2.2.4 Activity Representation

Tasks or activities available to an operator are contained in that operator’s UWR and generate a majority of the simulation behavior. Within MIDAS, an hierarchical representation is used (similar to, but more flexible than the Mission-Phase-Segment-Function-Task decomposition employed by many task analysis systems). Each activity contains slots for attribute values, describing, e.g., preconditions, temporal or logical execution constraints, satisfaction conditions, estimated duration, priority, and resource requirements. Resources include both physical effectors such as eyes, fingers, or hands, as well as the model of visual, auditory, cognitive, and psychomotor task loading described by Aldrich et al. [9].

A continuum of contingent or decision making behavior

Quick, skill-based, low effort responses to changes in values of information held in the UWR are captured by "daemons" when a triggering state or threshold value, sensed by perception, is reached. Daemons represent well-trained behaviors such as picking up a ringing phone or extinguishing a caution light. Classic production rule-based behavior is also available, and used when conditions in the simulation world match user-defined rule antecedent clauses active for the scenario modeled. Finally, more complex or optimization-oriented decision making is represented via a set of six prescriptive algorithms (e.g., weighted additive, elimination by aspect, etc.) as reported by Payne, et al. [11]. Each of these algorithms use a different combination of attribute values, weights, and cut-off values for calculating the “goodness” of the options.

2.2.5 Scheduler

Activities which have their preconditions met, temporal/logical execution constraints satisfied, and required information retrieved from memory are queued and passed to a model of operator scheduling behavior. Based on the user’s selected scheduling strategy (e.g., “workload balancing” or “time minimization"), activities are executed in priority order, subject to the availability of required resources. MIDAS contains support for parallel activity execution, the interruption of on-going activities by those of higher priority, and the resumption of interrupted activities. The specific design for this model of scheduling has been previously reported by Shankar [12].

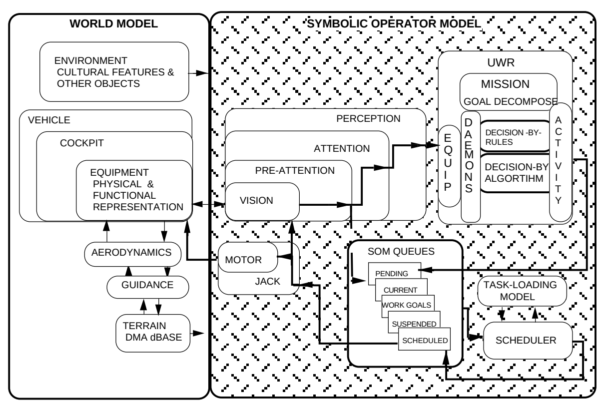

Figure 2. MIDAS Simulation Execution

To produce a stream of human-system behavior, the components described above execute during a mission simulation as depicted in Figure 2. The models for a vehicle, cockpit equipment, and gaming area comprise a World Model. The aggregation of MIDAS' separate human performance elements is termed a Symbolic Operator Model (SOM). In brief, information about the designated mission and vehicle equipment is uploaded to the simulated operator's Updatable World Representation (UWR) prior to execution. During each simulation time cycle (presently 100 ms), information from the world is filtered by perception, and passed to the UWR. The operator uses this sensed information as required by the activities. These activities are then scheduled, loaded, and passed to Jack® for execution, where they usually affect the cockpit or world state, prior to the cycle repeating. During a simulation, the user is provided quantitative data about activity execution, memory accesses, and workload, as well as a visualization of the simulated operator performing their tasks within the vehicle and world.

2.2.6 User Interface

MIDAS software is exercised through a user interface allowing most of the system to be accessed under a unified umbrella, avoiding the proliferation of individual editors which characterized previous versions of the system. The interface has two main aspects: top-level components that enable navigation among environments (e.g., Model Development, Simulation) and individual editors for specifying models (environment, vehicle, equipment, personnel). Top-level components are produced in HTML (Hyper-Text Markup Language), with links for navigating to and invoking a particular editor. Editors use Silicon Graphics' ViewKit widget set and Motif/X-Windows. A SearchView widget, for example, has list-based, outline, and graphical views of target data sets, and is the primary editor basis. This approach insures uniformity in both appearance and behavior, with an example shown below.

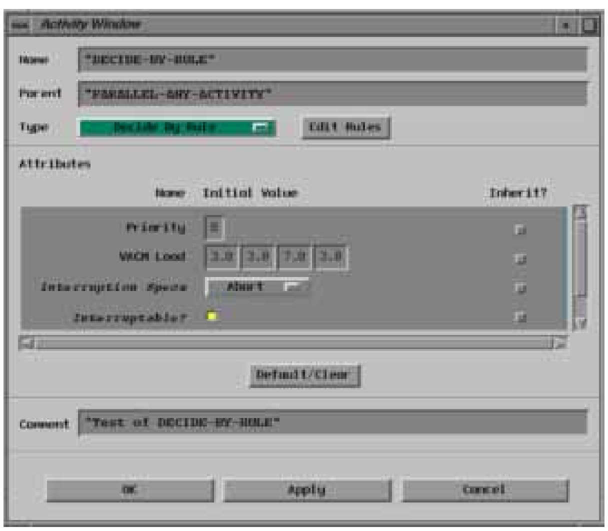

Figure 3. MIDAS Activity Editor Window

The MIDAS interface also includes a tutorial which guides users through an example analysis: selecting a domain, building equipment models, creating a human figure and graphic environment, choosing an activity stream, and running the simulation.

3. APPLICATIONS OF THE SYSTEM

The following applications of MIDAS were produced simultaneously with development of the software. While this approach fostered considerable tension between developers concerned with advancing the "core" system and those applying the existing prototype software, each application significantly increased the team's knowledge

proven, were folded back into the basic MIDAS system for reuse.

3.1 Nuclear Power Plant Design

MIDAS' first application examined advanced automation options for next-generation nuclear power plant consoles in collaboration with Westinghouse. Operator task sequences, timelines, workload, and interruption effects were studied in a scenario involving diagnosis of a steam generator fault. Two simulations were produced, comparing an existing layout and a design with an electronic checklist merged with one of the displays.

Fully reported by Hoecker et al. [13], this work was significant for several reasons. First, it demonstrated MIDAS' utility within a domain considerably different from the one it which it was developed. Secondly, the work included a new class of operator activities, "interruptions." Most task analyses employ a design-to scenario in which activities are assumed to occur in a rather ideal sense. While emergency procedures are often included in equipment evaluation, rarely are distracting, but normal, interruptions to operator task flow addressed. The MIDAS simulations concentrated on the Senior Reactor Operator (SRO) and included clarifying questions, requests for data, and delays associated with their communication to other members of the crew. These interruptions not only had the effect of delaying the SRO's activities, but also making it difficult to remember where they were in the prescribed procedural sequence. The MIDAS simulations showed the electronic checklist facilitated proper and rapid resumption of activities when interrupted. However, because the checklist display masked other information needed, the modeling also showed several periods of deleterious interaction which required operators to page between or scroll within displays to accomplish their activities.

3.2 Commercial Transport Operations

MIDAS has seen its most convincing and extensive use in the analysis of commercial air transport operations. Four major simulations have been performed. The first, called Air-MIDAS, studied crew ATC clearance processing with voice and datalink communication, under differing flight path automation options. Motivated by other terminal airspace utilization work, this simulation was designed to answer two basic lines of inquiry. First, the system was used to identify how close to a desired descent point a flight crew could receive and implement a new clearance while still using the most sophisticated and fuel-efficient form of flight path control (a flight management computer). Secondly, MIDAS was used to quantify the incremental effects of manipulations in several variables of interest, namely, weather, traffic, and task interruptions.

To accomplish these aims, new stochastic elements were added to the basic MIDAS software. Sequences and task times were created, probabilities for various forms of interruption were added, and the entire study was exercised within a new monte carlo/parametric study framework. Additionally, since ATC clearance processing was shared between the pilot and copilot, the simulation was run with a composite crew, that is, a single entity representing the combined resources, knowledge, and activity of two individual operators. The simulation study was run with 100 replicates for each factor-level combination in the design. The flight crew's success completing the clearance within the time allowed, and the automation mode used in that process, were dependent variables. Summary results are found in Figure 4, with a full report of the Air-MIDAS study available in Corker and Pisanich [14]. The data show a rapid decrease in successful performance when a clearance is issued closer than eight miles from the desired descent point. Further, with voice communication, simulated crews shifted earlier from the flight management system (CDU) to a simpler form of automation (MCP). Results from this MIDAS simulation were precisely those needed by terminal area automation developers to define desired clearance issuance windows.

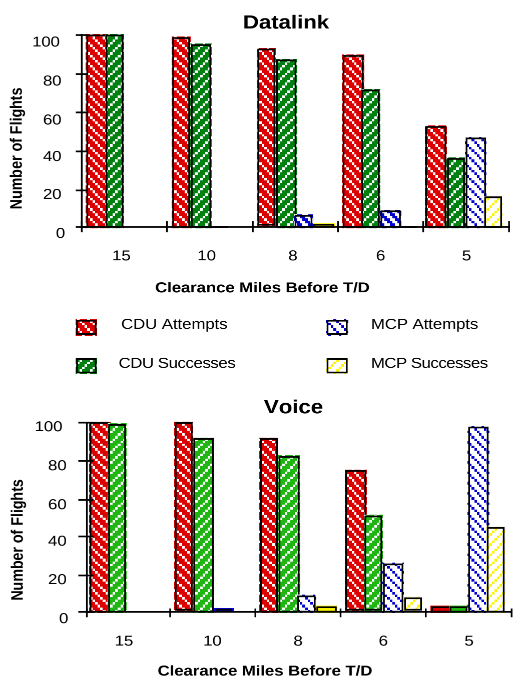

Figure 4. Effects of Communication Medium and Distance on Flight Path Automation Successes

3.2.1 Model vs. Human Performance

An extension of the application described above was used to compare performance predictions from modeling with those from a piloted simulator study. A flight crew modeled in MIDAS "flew" descent profiles with the same conditions of speed, crossing restriction, and distance to top of descent experienced by four human crews in a 747-400 simulator. A split-halves method was used, in which activity durations within MIDAS were derived from one-half of the subject data. The model was then checked for consistency with the remainder of the human performance in the same performance regimen. Since the scenario included receipt of a descent clearance, the crew's decision whether and how to enact it, and their preparation of aircraft systems, a key measure is the time between the completion of required activity and the actual descent point. This variable is the "spare time" a crew has between enacting a clearance and its required completion time.

Shown in Figure 5, three comparisons were made with this measure using the t test. First, the behavior of the model across the experimental conditions was contrasted with the performance of the flight crew in the same conditions (split-halves comparison). Second, one model run was compared with cumulative data from the four model runs to check internal consistency of the model (cumulative model data vs. single run). Finally, the accumulated human data were compared to a single model run, chosen at random, to see if there was an effect on the model variance encountered by summing across model runs (flight crews vs. simulation run). In all cases, the test statistic (df = 14) revealed no significant differences between data sets. Detailed discussion of the experiment and results is in Corker and Pisanich [15]. These data suggest MIDAS is predictive of flight crew performance across the conditions of the scenario modeled and encourage further development and application of the tool.

	t	p (T<t)=0.05 two-tailed
Split-Halves	1.286	0.23
Cum. Model vs Single Run	1.088	0.29
Flight Crew vs Single Run	1.017	0.33

Figure 5. Model vs. Human Subject Data

3.2.2 Advanced Air Transport Technology

Drawing from the civil transport operations work above, a major MIDAS application is on-going under the FAA/ NASA AATT program. A goal of this effort is to move toward a "free flight" concept, relaxing restrictions for use of the national airspace. MIDAS has been used to examine constraints and requirements for controlled airspace, traffic alerting, and decision aids.

A major thrust of this work has been advocating design practices which incorporate human factors, as well as demonstrating the role for constructive simulation in that process. Figure 6 illustrates this concept, and was the basis for a MIDAS study concluding that protected zones around aircraft should include human performance constraints in the designs for alerting and awareness systems for aircraft self-separation.

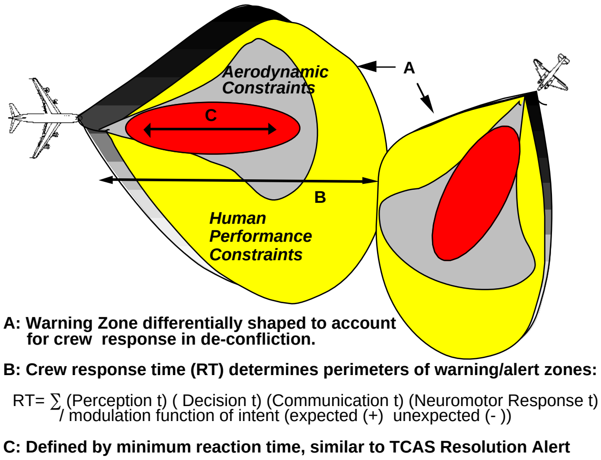

Figure 6. Human Performance Contribution to Advisory Bubble Shape, Size, and Dynamics

Because this domain involves large numbers of aircraft, crew, and ATC operators, a number of enhancements to MIDAS have been developed for this challenge. The AATT work is prototyping the first multiple operator simulations (two aircrew, two controllers), the first model of auditory communication (using a time buffer approach), as well as introducing a new activity class called "expectations," through which an operator is primed to repeat a procedure or request additional information when a satisfactory response from another human or equipment is not received. A full report of these results and the new modeling elements will be published later this year.

3.3 Short Haul Civil Tiltrotor (SHCT)

MIDAS is being applied to the SHCT through a cooperative agreement with Boeing Helicopters Division. The software is undergoing a form of alpha-testing, with engineers at Ames and Boeing applying the system to layout and procedural issues associated vertiport operations, represented in Figure 7. Presently under study are various forms of nacelle tilt control during descent, with the simulations to be completed later this year.

3.4 Air Warrior.

The Army's Air Warrior program is a next-generation aircrew life support equipment ensemble entering concept development. MIDAS was selected as part of a battery of piloted simulations and models which established baseline performance measures and specification requirements. Both crew station geometry evaluations and a procedural simulation were performed with MIDAS. Assessments were performed in both unencumbered (normal summer weight flight suit) and encumbered conditions (present generation cold weather, Mission Oriented Protective Posture (MOPP) apparel), within a model of the AH-64D Apache Longbow cockpit The two suit conditions were simulated with the Jack® human figure model, using data for girth and joint limits from US Army anthropometry studies [16]. An aviator in the MOPP ensemble next to a simulated figure and apparel are shown in Figure 8.

Figure 8. Human and Model in MOPP Gear

The MIDAS study isolated specific areas within the cockpit which posed reach problems. With the shoulder harness locked, the smallest stature body failed to reach eight of nine critical cockpit switches, even with full seat adjustment. Further, vision polars produced showed a restricted FOV (80x90 deg.) with the MOPP protective mask, versus the unobstructed view shown in Figure 9.

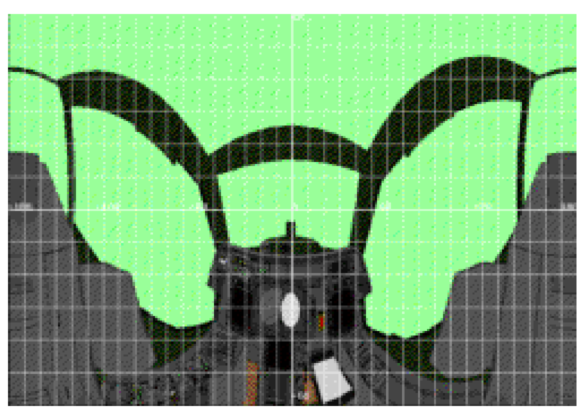

Figure 9. Rectilinear Plot, CPG Design Eye, AH-64D

This finding was supported by pilot comments that activities in MOPP gear, such as clearing around the vehicle, were fatiguing, since greater body and neck movement was required to achieve the needed field-of-regard [17]. This reference to Atencio, et al., has a thorough discussion of the Air Warrior application.

For the MIDAS procedural simulation, the modeled AH-64D co-pilot gunner performed a range of tasks during an 8-10 minute vignette in an attack mission. The scenario was run with the model sized by stature as a 5th percentile female and a 95th percentile male. Asserted fine motor error rates for switch actuation (20%, 30%, 40%) were combined with apparel and crossed with the two body sizes, producing eight simulation experiment runs. The simulations each contained over 400 discrete activities such as display fixations, control manipulations, and crew decisions. Data supporting aggregate measures of performance were collected and reported, quantifying workload, exposure time, and total mission time effects from each simulation experiment permutation. The MIDAS Air Warrior study was the most ambitious application undertaken with the system. More than three workyears were devoted to this effort, producing the most extensive cockpit and procedural modeling to date.

4. NEW MIDAS DESIGN

Although application directed work with the existing software comprises half of the program's funding, a major effort to rearchitect the MIDAS system is also underway. The goals driving this redesign include decreasing development time for new scenarios (from several months to one or two weeks), increasing the efficiency of the running system (from around 50 times real-time to near real-time), facilitating the process of replacing cognitive and perceptual models (from weeks to days), and expanding the functionality of the system as detailed below.

Presently, MIDAS is implemented in a combination of C/C++ and LISP, with the human performance elements being largely LISP-based. As a result, supporting the interaction of modules in different languages and trying to map design concepts uniformly across very different programming paradigms (e.g., the notion of agent), has proved difficult. In addition, while it began with a fairly rigorous design process, over the years MIDAS has acquired a number of idiosyncratic and hard-wired features, simply due to time constraints and the nature of complex software evolution. The resulting system is difficult to learn, maintain, and modify. There was also a desire to update the human operator model—in particular to account for more widely accepted views on human information processing and its likely underlying architecture.

For these reasons, a research phase is underway with the goal of redesigning MIDAS using object-oriented techniques and implementing the system entirely in C++. While human factors analysis will remain the key purpose described applications and other research in human modeling demanded expanded functionality for the system in several areas. These included enhancements of the human operator model to encompass more complete notions of attention and working memory, as well as support for modeling multiple human operators and their interactions. Further emphasis also needed to be placed on the human-computer interface of the system, as well as adding an explicit simulation analysis environment to enable a more complete examination of simulation results.

The approach taken in MIDAS' redesign is object-oriented rapid prototyping. Initial design efforts produced a high-level system architecture, shown in Figure 10, with the following elements: a domain model supporting components necessary for running a simulation; a graphics system to enable simulation visualization; an interface for end user specification of the target domain models; a simulation system for controlling the simulation and collecting data therefrom; and a results analysis system for examining simulation data after it has been collected.

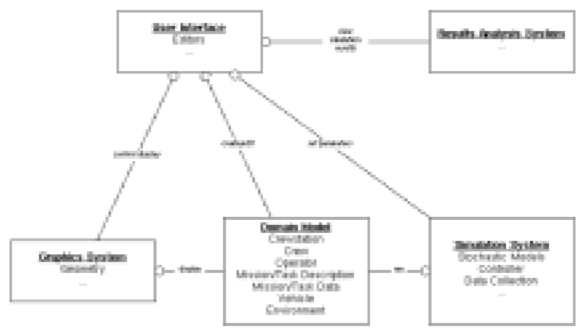

Figure 10. Top-level Design of New MIDAS

The domain model is centered on a crew station, with the following models: the environment encompassing the crewstation; the vehicle containing the crewstation; the crewstation itself, particularly its contained equipment; and the crew, meaning the human operators together with their assigned missions and procedures. Figure 11 depicts these domain elements in object-oriented notation.

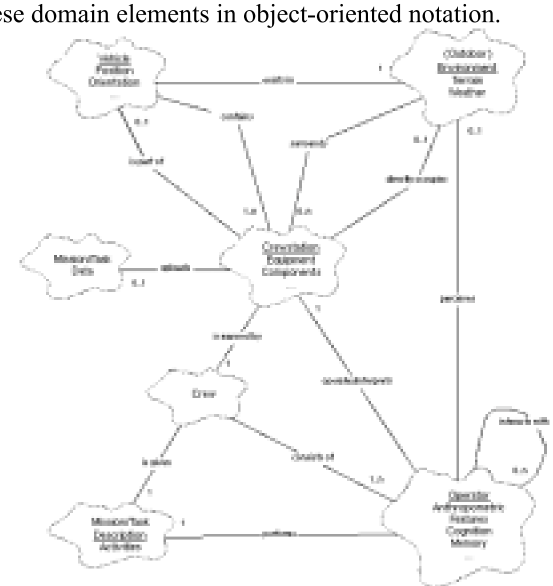

Figure 11. Domain Model Objects and Relationships

first release took place in Nov. 1996 and focused on developing a simplified running domain model, including basic elements of geometry, environment, vehicle, crewstation equipment, and a single human operator. Later releases will expand the modeling and add major features such as the end user interface, simulation control and analysis, and expanded libraries of domain models accessible within an object-oriented database. Subsequent sections provide further information on primary domain components as they have been realized in the first release.

4.1 MIDAS Geometry

The geometry component supports the rendering of physical aspects of a simulation, including the vehicle, equipment, and human operator. This component allows the MIDAS user to visualize what is happening during a simulation in order to directly assess design effectiveness. At a high level, the goals for this component involve avoiding a dependence on any one graphics library, maximizing portability, maintaining adequate efficiency for simulation viewing, and providing the capability for turning the graphics off without undermining the simulation (for example, when simple data collection is all that is required). The geometry class structure consists of node hierarchies of primitive types (such as 2-D and 3-D points, vectors, textures) and composite types (such as areas, polygons, text) which form geometries associated with MIDAS domain objects. These domain objects are in turn part of a MIDAS scene, which can then be observed on the computer screen through a Viewer. The rendering of these geometries is done through SGI's Open Inventor.

4.2 MIDAS Environment

The environment represents the external "field", both physical and conceptual, in which domain entities live. Conceptually, it is a container through which MIDAS domain entities can be accessed. Physically, it defines a gaming area in which any entity physically modeled exists. Within a given simulation environment, modeled aspects include features such as trees or telephone poles, buildings, terrain, weather, vehicles and vehicle routes. Geometric attributes are associated with these environment entities so that they can be viewed during the simulation. MIDAS' new environment representation and vehicle model, described below, are similar to the existing design, however they are implemented in object-oriented methods.

4.3 MIDAS Vehicle

A vehicle is a moving object which may contain a crew station being modeled, with several vehicles possible in one simulation. Each vehicle moves along at most one route, an ordered list of waypoints representing its desired path, with an itinerary being generated to capture the actual path taken (e.g., to avoid obstacles, etc.). Guidance models are included which capture effects of the vehicle's motion controls. Guidance can be realized as an autopilot, as physical controls operated by a human, or some input, and effects the vehicle through a dynamics model. The latter computes a vehicle's location based upon input from the guidance model plus weather and terrain conditions. The dynamics model in turn passes on information used to update crew station and guidance models. The final MIDAS release will include vehicle models for rotorcraft, tilt-rotor, and fixed-wind transports.

4.4 MIDAS Crewstation Equipment

A crew station is a work area supporting one or more operators (such as an aircraft cockpit with a pilot and co-pilot) and containing the equipment used to monitor and control the corresponding vehicle or function. The equipment model in turn is a collection of related components that simulate the functionality of the equipment of a given crew station. The goals for this model's redesign include minimizing the programming required by a designer to assemble an equipment model, allowing this to be done from libraries of domain-specific equipment, and decreasing the associated development time. Whereas earlier versions of MIDAS used three forms of equipment models (time-scripted, stimulus-response, and finite state machine), the new design combines these into one class called discrete state components. It also adds a new type, called continuous components, capturing behavior that could not be represented by a reasonable number of discrete states. Each type of component is composed of behavior, perceivable attributes, relationships with other components, and animation aspects, including geometry and a method for updating its appearance. An example of a discrete state component is a multi-function display, where each page is a state from which other pages can be reached via button presses. A continuous component would be an torque gauge or altimeter, where the indicator can assume any value within its range of motion. These types of components are combined in various ways to capture more complex cockpit equipment.

4.5 MIDAS Human Operator Model

In the redesign, the modeled human operator is both expanded in functionality and aligned more closely to typical information processing models of human cognition and perception. The model includes an anthropometric component, capturing physical aspects of human behavior, permitting visualization of reach, fit, and fixation activities, for example, as well as internal processing models for perception and cognition. Referenced above, the previous MIDAS anthropometric component was Jack®. In the new design's first release, a simple representation of the operator's hands and head was used, although this may be replaced by a more complete model in the future.

The processing architecture of the human operator model has input, memory and central cognition, output, and attentional components (see Figure 12). Operator input is received from the environment through the senses only visual input was modeled). Visual input is obtained through an intermediary, the Visual Scene, which contains all objects potentially visible to the human operator, either inside or outside the crew station. The information that enters the operator's eyes depends on the ambient conditions, as well as any filters or vision-enhancing equipment.

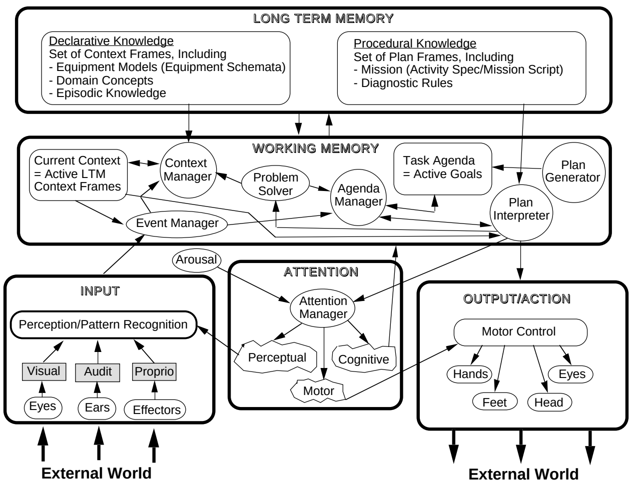

Figure 12. New MIDAS Operator Architecture

Auditory input occurs through an intermediary object called the Auditory Field, containing all signals and messages emitted by equipment, other operators, and the environment. What the operator hears depends upon proximity to the emitting source and related equipment. The Perception element processes these inputs to produce a simple interpretation which is entered into Working Memory in either the Phonological Loop (linguistic material) or the Visuo-Spatial Sketchpad (non-linguistic material), along the lines of the Baddeley model [18].

Memory now consists of both long-term and working memory components. The former, similar to the existing UWR, contains both declarative and procedural knowledge. Declarative knowledge includes both facts the human operator may know (e.g., current vehicle location), as well as context frames capturing typical situations an operator might encounter in the target domain (e.g., processing a pre-flight checklist, flying through turbulence). Procedural knowledge is represented as Reactive Action Packages or RAPs, after the work in robotic planning by Firby [19]. RAPS describe how to accomplish a given goal and consist of the methods possible for achieving that goal, when each is most appropriate (according to the current context), and how it is known that the goal is satisfied. RAP methods can be either further subgoals, decisions which require reasoning, or motor primitives which can be directly executed by the motor output processes. In earlier versions of MIDAS, human activities had to be specified completely for the entire scenario down to the activity primitive level. The reason for changing to the RAPs approach was to allow endusers to work with more abstract activities in describing human operator behavior and to allow more emergent behavior from a simulation, driven by context

The other, active portion of memory, or Working Memory, has two main contents. One captures the Current Context (retrieved from Long-Term Memory and instantiated from sensory input) and the other, the Task Agenda, indicates the currently active goals. The types of central processing that occur related to the Working Memory contents include the following: 1) event management - new inputs are assessed to determine whether they were expected or not; if so, they are simply used to update the Current Context; if not, they generally trigger the creation of new goals to handle an unexpected event; 2) agenda management: the goals on the Task Agenda are examined, based upon priority and the current situation, to determine which one to focus on next; 3) plan execution - once a goal is selected, it is used to retrieve the appropriate RAP from Long-Term Memory, and this is in turn executed by selecting and "unpacking" the best method on the basis of the Current Context; if the selected method consists of further goals, these are simply added to the Task Agenda, if they are primitive actions, these are passed onto the Motor component for execution.

Bodily movement, manipulation of equipment, and speech output is regulated by the Motor Control process. If required resources are available, a motor activity is created and processed, with both the operator's physical actions and their effects on equipment and/or environment objects modeled. Activities such as manipulating equipment, fixating on an object, or making a speech utterance are all supported as primitive motor outputs.

Within the new architecture, Attention is planned as a limited central resource. Therefore, for any of the behavior described previously to occur, the responsible process must first secure the necessary attentional resources. If these are not available, then delay of that process, or an interruption of an ongoing activity, is necessary. While the goal of this approach is a considerable expansion of the previous attention and VACP loading models within MIDAS, details for the design are still under development.

4.7 Future Plans

As mentioned earlier, an integrated, comprehensive interface was previously developed for the existing system. A major focus of the next software release will be to extend this work as required for the new model components within MIDAS. Subsequent releases will complete the prototyping of content, with the final software build occurring in twelve months, prior to a period devoted exclusively to model verification and usability evaluation. Following that activity, follow-on options for MIDAS include: 1) adding a head mounted display interface, allowing users to immerse themselves in a crew station and mission from a viewpoint inside the design, 2) making the system compliant with distributed interactive simulation protocol and the emerging high level architecture standards, and 3) teaming with a vendor to commercialize portions of the system for distribution.

MIDAS has demonstrated that, while nascent, human performance modeling can greatly aid the design of complex human-machine systems. Advances in the understanding and modeling of human behavior must occur before this form of constructive simulation sees widespread interest, however, pay-offs to future crew station and procedure design are clear from the applications presented. Within the global aviation system, automation and decision aiding systems are being introduced at a rate which overwhelms our ability and apparatus to assess them empirically. MIDAS' modeling of operator behavior at a process level, together with explicit representations for crew station controls and displays, mission tasks, and context, is a promising method to achieve the proper integration of human and equipment function.

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